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CROP PRODUCTION

Organic cultivation of onion under castor cake fertilization and irrigation depths

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ABSTRACT. Two experiments were carried out to evaluate the effects that different doses of castor bean (0, 200, and 300 g m^{-2}) and irrigation levels (204, 224, 278, and 321 mm in 2014, and 278, 302, 397, and 444 mm in 2015) have on both the productivity and quality of onion bulbs. In the experiments, the experimental design was randomized blocks (4 x 3 factorial scheme), with five replicates. Irrigation management was performed using a Simplified Irrigation Device (SID) in response to soil water tension in the treatment of highest irrigation depth. The following variables were evaluated: plant dry biomass (PDB), bulb dry biomass (BDB), total yield (TY), mean bulb fresh weight (MBFW), mean bulb dry weight (MBDW), mean bulb diameter (MBD) and water use efficiency (WUE). The highest irrigation depths positively influenced the mean production of onion bulbs, regardless of the applied dose of castor cake. The doses of castor cake positively influenced the production of onion bulbs when higher irrigation depths were applied.

Keywords: *Allium cepa* L., water deficit, organic fertilization, irrigation automation.

Cultivo orgânico de cebola sob adubação com torta de mamona e lâminas de irrigação

RESUMO. Foram realizados dois experimentos com objetivo de avaliar o efeito de diferentes doses de torta de mamona (0, 200 e 300 g m^{-2}) e lâminas de irrigação (204, 224, 278 e 321 mm, em 2014 e 278, 302, 397 e 444 mm, em 2015) na produtividade e qualidade de bulbos de cebola, nos anos de 2014 e 2015. Nos experimentos o delineamento experimental foi em blocos casualizados (fatorial 4 x 3), com cinco repetições. O manejo da irrigação foi realizado pelo "Acionador simplificado de irrigação" (ASI), em resposta à tensão de água no solo, no tratamento de maior lâmina. Foram avaliadas a biomassa seca de planta (BSP) e de bulbo (BSP), a produtividade total (PT), o peso médio fresco de bulbo (PMFB), o peso médio seco de bulbo (PMSB), o diâmetro de médio dos bulbos (DMB), a eficiência de uso da água (EUA). As maiores lâminas de irrigação influenciaram positivamente a produção de bulbos de cebola, independente da dose de torta de mamona aplicada. As doses de torta de mamona influenciaram positivamente a produção de bulbos de cebola quando maiores lâminas de irrigação foram aplicadas. A EUA não foi influenciada pelas lâminas.

Palavras-chave: *Allium cepa* L., déficit hídrico, adubação orgânica, automação da irrigação.

Introduction

Onion occupies a prominent position among bulbous vegetables and has the great economic importance in the world (El Balla, Hamid, & Abdelmageed, 2013). It is considered the third most important vegetable in economic value in Brazil (Cecílio Filho, May, Pôrto, & Barbosa, 2009). It is the main agricultural activity of more than 60 thousand families, and almost 100% of its production area is subjected to irrigation, except in the south region of the country (Ribeiro, Carvalho, Santos, & Guerra, 2016).

Because the cultivated area of onion is increasing worldwide, irrigation systems must be optimized, especially in arid and semi-arid regions (Zheng et al., 2013). In this context, studies to characterize the adequate water depth for the onion crop have been conducted, and their results indicate that higher yields occur when the soil is maintained with moisture close to field capacity (Channagoudra, Prabhudeva, & Kamble, 2009; Martin de Santa Olalla, Domínguez-Padilla, & López, 2004; Shock, Feibert, & Saunders, 2000).

Applying moderate water restriction to an onion crop aims to anticipate the beginning of bulb formation and the end of the crop cycle, which may be beneficial, depending on the purpose of the cultivation. However, the yields decrease when the water deficiency coincides with the beginning of bulb formation, which is considered the critical period for crop development (Zheng et al., 2013). The management of nutrients and irrigation directly influences the onion yield, the maturity stage of the plants and the harvest (Tekalign, Abdissa, & Pant, 2012; Leskovar, Yoo, & Pascual-Seva, 2012), and it interferes with the size, quality, sprouting percentage and total mass of the bulbs. However, few studies have analyzed the effects that water availability and application have on the performance of organic fertilizers. The soil moisture affects the mineralization process of these materials, resulting in a greater release of nutrients, especially nitrogen (N) (Lima et al., 2011), which increases the productivity of onion bulbs (Boyhan, Torrance, & Hill, 2007; Resende & Costa, 2008).

The organic production of onion is technically feasible when using organic materials, such as castor cake, that provide all of the nutrients required for its growth (Costa, Araujo, Santos, Resende, & Lima, 2008). Castor cake is a byproduct of castor oil extraction (Magriotis et al., 2014); it contains 4.15, 0.61, and 0.96% of N, P, and K, respectively, and has a C/N ratio of approximately 11.6 (Zapata, Vargas, Reyes, & Belmar, 2012). Thus, it is considered a high-quality fertilizer (Lima et al., 2011). This material has been widely used in the production of vegetables in organic systems (Santos, Espíndola, Guerra, Leal, & Ribeiro, 2012).

This study was undertaken to further evaluate the interactive effects that different irrigation levels and doses of castor bean cake have on the productivity and quality of onion bulbs in an organic production system.

Material and methods

Two experiments were carried out from May to October in both 2014 and 2015, at the experimental field of the “Fazendinha Agroecológica”, km 47, in the municipality of Seropédica, Baixada Fluminense of Rio de Janeiro State, Brazil (22°45` S; 43°41`W; 33.0 m). The climate of the region is tropical and is classified as Aw according to Köppen’s classification. During the experiments, the mean values of temperature and relative air humidity were 22.0°C and 72.9% in 2014 and 23.4°C and 77.2% in 2015. The cumulative rainfall was 128 mm in 2014 and 160 mm in 2015 (Figure 1).

The experiments were conducted in Red Yellow Argisol, with a sandy loam texture (Embrapa, 2006), which showed, in the 0 - 0.2 m layer, a soil density of 1.42 g cm^{-3} and contents of clay, sand and silt of 14, 70, and 13 g kg^{-1}, respectively. The soil chemical characteristics were the following: pH: 6.2; Al, 0.0 mmol$_c$ dm^{-3}, Ca: 37 mmol$_c$ dm^{-3}, Mg: 16 mmol$_c$ dm^{-3}, K: 120 mg dm^{-3}, and P: 54 mg dm^{-3} (mean of 2014 and 2015). Minimum cultivation was adopted as the soil tillage.

The sowing of onion (cv. Alfa tropical) and its transplanting were performed in May and late June, respectively, in both 2014 and 2015. Basal fertilization was performed using aged bovine manure (1.0 kg m^{-2} of dry matter per plot), whose chemical characteristics were the following: N: 18.5 g kg^{-1}, P: 4.2 g kg^{-1}, K: 14.5 g kg^{-1}, Ca: 9.4 g kg^{-1}, and Mg: 7.7 g kg^{-1} (mean of 2014 and 2015).

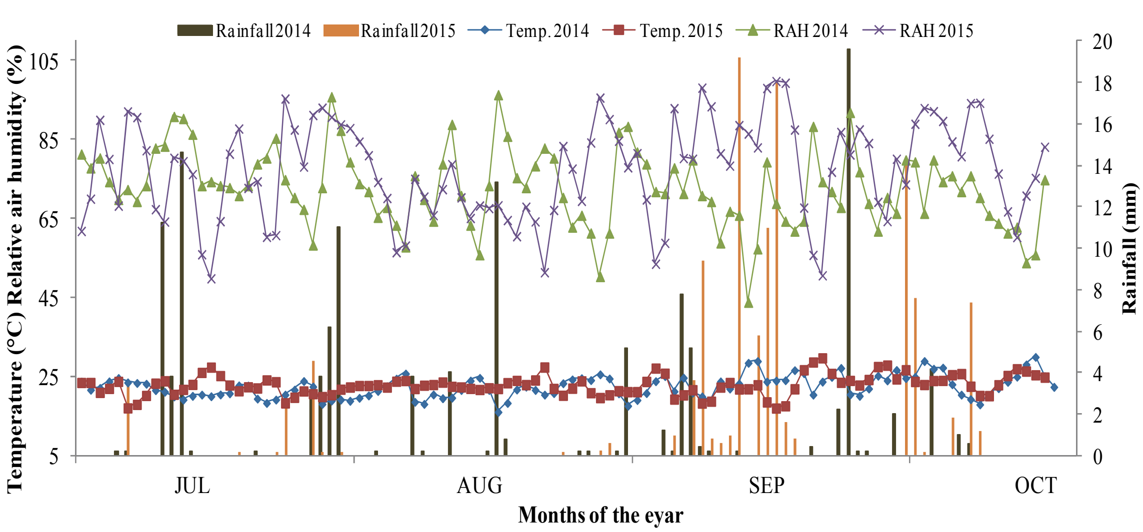

Figure 1. Mean temperature, relative air humidity and rainfall in the cultivation periods in 2014 and 2015.

The plots were arranged in 1-m^2 beds, spaced by 0.50 m of border and cultivated with 40 plants each, with a spacing of 0.10 m between plants and 0.25 m between rows. Cultivation practices consisted of manual weedings and phytosanitary control using Bordeaux mixture and roguing.

The different irrigation depths were applied through a drip system, using emitters ("iDrop normal"/Irritec) with nominal flow rates of 2.0 and 4.0 L h^{-1} that were adjusted at different spacings. Irrigation management was performed using the "Simplified Irrigation Device" (SID) (Medici, Rocha, Carvalho, Pimentel, & Azevedo, 2010), which operates in response to soil water tension and is regulated by the unevenness between a porous capsule and a pressure switch.

The adopted experimental design was in randomized blocks, in a 4 x 3 factorial scheme with five replicates. The treatments consisted of irrigation depths (L1- irrigation depth applied by the SID, L2 - 83% of L1, L3 - 50% of L1, and L4 - 42% of L1) and doses of castor cake as top-dressing (A - 0 g m^{-2}, B - 200 g m^{-2}, C - 300 g m^{-2}), equivalent to 0, 136.6, and 204.9 kg of N ha^{-1}. The chemical analysis of the castor cake showed the following nutrient contents: N: 68.3 g kg^{-1}, P: 9.4 g kg^{-1}, K: 14 g kg^{-1}, Ca: 5.4 g kg^{-1}, and Mg: 6.1 g kg^{-1} (mean of 2014 and 2015). Top-dressing fertilizations were performed at 30 and 55 days after transplanting (DAT) in 2014 but only at 30 DAT in 2015.

From transplanting to harvest, the SID was regulated to actuate the irrigation system when soil water tension was approximately 12 kPa in the L1 treatment. The soil water tension was monitored daily by using puncture tensiometers.

Irrigation actuation was simultaneously performed for each block, and the volume applied in the plots was daily monitored with hydrometers (Alpha mnf /FAE). The irrigation depths for each of the evaluated treatments were obtained based on the ratio between the water volume and either the wetted area (until 45 DAT) or the area shaded by the plant (from 46 DAT to harvest).

The accumulations of dry biomass in the plant (PDB) and in the bulb (BDB) were evaluated from 40 DAT onward, at 20-day intervals. Shoots, bulbs and roots were dried in a forced-air oven (70°C) until reaching a constant weight. To evaluate the total yield (TY), the mean bulb fresh weight (MBFW), mean bulb dry weight (MBDW) and mean bulb diameter (MBD) were measured transversely, and 16 bulbs per plot were collected and classified into four categories (> 60 mm, 60 to 41 mm, 40 to 30 mm and < 30 mm) (Kumar, Imtiyaz, Kumar, & Singh, 2007).

Water use efficiency (WUE) was obtained by calculating the ratio between TY and the water depth received by the crop (irrigation + rainfall), and the irrigation water use efficiency (IWUE) was obtained by calculating the ratio between TY and the irrigation depth (Lovelli, Perniola, Ferrara, & Tommaso, 2007).

The data were subjected to analysis of variance and regression; when significant, the fits were presented.

Results and discussion

In response to the development of culture and the soil and climatic conditions of the region, the irrigation system was activated by the SID 48 times during the onion crop cycle in 2014 and 53 times in 2015, applying irrigation levels plus rainfall of 204 (L4), 224 (L3), 278 (L2), and 321 mm (L1) in 2014, and 278 (L4), 302 (L3), 397 (L2), and 444 mm (L1) in 2015.

Evaluating the onion yield under the same edaphoclimatic conditions but with different soil covers and irrigation depths, as estimated through the soil water balance with a TDR, Ribeiro et al. (2016) obtained water depths of 372 and 351 mm (100% of crop evapotranspiration) in the absence and presence of soil cover, respectively. Marouelli, Abda, Madeira, Silva, and Oliveira (2010), in a study conducted in Brasília during the dry season of 2007, applied water depths of 525 and 625 mm in onion cultivation (cv. Baia Periforme) under no-tillage and conventional systems, respectively.

The growth dynamics of the crop in response to the different irrigation depths exhibited the same tendency in both cultivation years. The PDB was influenced from 100 DAT (Figure 2A), whereas the irrigation depths L1, L2, and L3 (9.0 g $plant^{-1}$) did not exhibit significant differences among themselves but did differ from L4 (6.3 g $plant^{-1}$). At 120 DAT, differences in PDB were observed among the highest (L1 and L2) and lowest (L3 and L4) irrigation depths (9.9 and 6.7 g $plant^{-1}$, respectively).

At the highest irrigation depths (L1 and L2), the accumulation of PDB increased during the cultivation period, but the same did not occur at the lowest irrigation depths (L4 and L3), which promoted a slight stagnation at 80 and 100 DAT, respectively, due to the reduction in the dry matter of leaves, bulbs and roots. These results demonstrate that the application of smaller irrigation depths activates the natural process of leaf senescence (Kumar et al., 2007, Zheng et al., 2013).

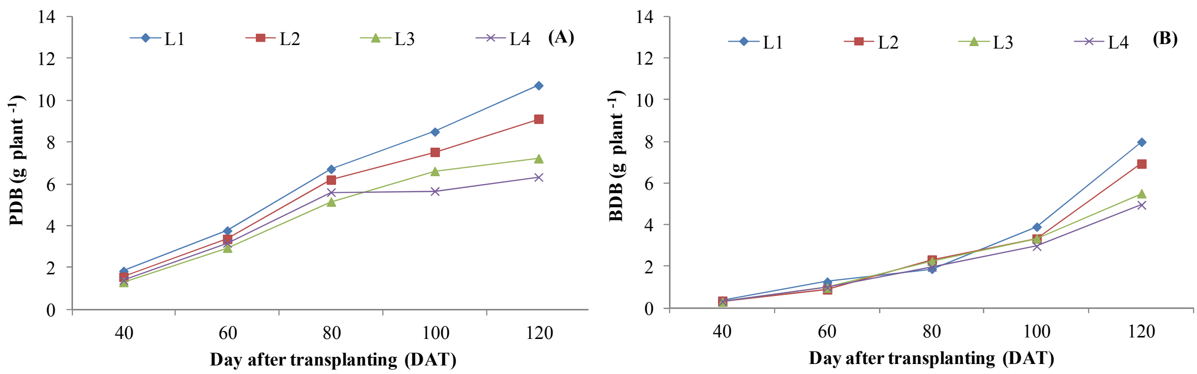

Figure 2. Plant dry biomass (PDB) (A) and bulb dry biomass (BDB) (B) in different development stages for irrigation depths at each dose of castor cake in both cultivation years (means of 2014 and 2015).

From the highest to the lowest irrigation depth, the PDB varied from 5.6 to 8.4 g plant^{-1} and from 6.3 to 10.7 g plant^{-1} at 100 and 120 DAT, respectively. In the cultivation of onion in Northern Minas Gerais, southeastern Brazil, Vidigal, Moreira, and Pereira (2010) obtained PDB values of 6.3 and 9.1 g plant^{-1}, respectively, at 101 and 122 DAT. Neto et al. (2014) obtained 14.5 g plant^{-1} at 90 DAT, for the cultivar IPA 11, when evaluating the growth and accumulation of macronutrients in the onion crop in Baraúna (Rio Grande do Norte State) and Petrolina (Pernambuco State). These variations in PDB are possibly attributed to the different cultivars and edaphoclimatic conditions of the cultivation regions.

BDB varied progressively during the cultivation period, regardless of the applied irrigation depth (Figure 2B). At 120 DAT, significant differences were observed, especially between L1 (higher BDB) and L3 and L4 (lower BDB). Bulb diameter is directly related to the amount of water applied (Kumar et al., 2007; Martin de Santa Olalla, Juan Valero, & Fabeiro Cortés, 1994). At 100 DAT, the BDB values obtained for different irrigation depths were similar to those found by Neto et al. (2014) (4 g) for the cultivar Texas Grano 502 and were lower than those of the cultivar IPA 11 (12.5 g).

In both cultivation years, regardless of the dose of castor cake applied as top-dressing, the irrigation depths significantly influenced the TY, MBFW, MBDW and MBD of the onion (Figure 3). Igbadun and Oiganji (2012), Ramalan, Nega, and Oyebode (2010) and Ribeiro et al. (2016) observed that irrigation depths had similar effects on the yield of onion bulbs.

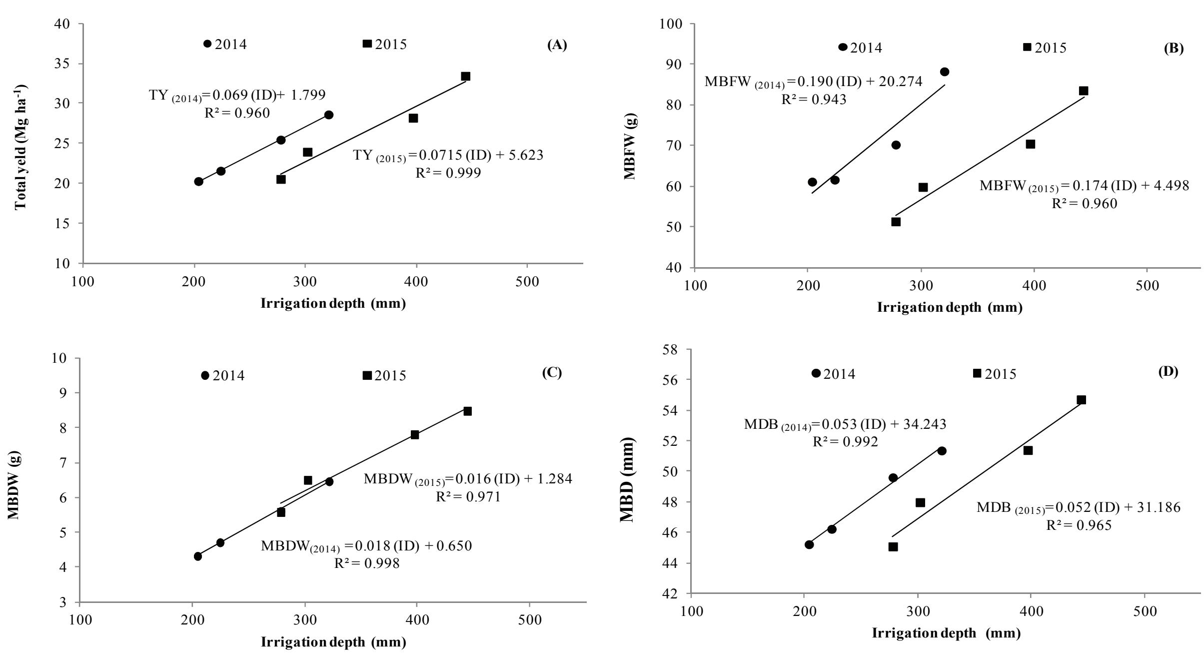

Figure 3. Total yield (TY) (A), mean bulb fresh weight (MBFW) (B), mean bulb dry weight (MBDW) (C) and mean bulb diameter (MBD) (D) for the irrigation depths at each dose of castor cake in both cultivation years (2014-2015). ID: Irrigation depth.

The reduction in irrigation depth of 36% (321 to 204 mm) in 2014 and of 37% (444 to 278 mm) in 2015 resulted in losses of 29, 30, 33, and 11% and 38, 38, 34, and 17% in TY, MBFW, MBDW and MBD, respectively, in each year. These results indicate that any degree of water stress can damage onion yield. A water deficit promotes numerous physiological alterations, such as a reduction in root mass, leaf area, number of leaves and, consequently, yield (Mao et al., 2003).

The castor cake significantly influenced TY (31.9 Mg ha^{-1}), MBFW (96.4 g), MBDW (7.4 g) and MBD (53.4 mm) in the cultivation of 2014, but only at the applied irrigation depth of 321 mm. A similar effect was observed in 2015 for TY (on average, 35.1 Mg ha^{-1}) and MBFW (on average, 87.9 g) at the highest irrigation depths (444 and 397 mm), for MBDW (9.5 g) at the irrigation depth of 444 mm and for MBD (52.2 mm), regardless of the applied irrigation depth (Figure 4). The significant effects of fertilization with castor cake as top-dressing only occurred at the highest irrigation depths because the moisture affects its mineralization, which results in the greater release of nutrients, particularly N (Lima et al., 2011). Boyhan et al. (2007) report that N fertilization has a strong impact on onion production and is necessary to obtain higher bulb yields.

The application of 200 g m^{-2} of castor cake did not promote the expected responses for TY, MBFW, MBDW or MBD (Figure 4), due to the high incidence of two leaf fungal diseases (Anthracnosis *Colletotrichum gloeosporioides f.sp. cepae* and Purple spot *Alternaria porri*) during this treatment, especially in 2014, when rainfalls occurred with higher frequency during the cultivation period (Figure 1). The statistical analysis showed low coefficients of determination (R^2) for the variable MBDW (Figure 4C), possibly because the source-sink relationship was damaged by the loss of photosynthetic apparatus caused by the diseases (Taiz & Zeiger, 2009). The degree of susceptibility of onion to diseases may be related to the mineral nutrition of the crop (Kurtz & Ernane, 2010).

In the present study, the highest TY values were 31.9 (2014) and 39.8 (2015) Mg ha^{-1} for irrigation depths of 321 (2014) and 444 (2015) mm, respectively, with the application of 300 g m^{-2} of castor cake. Costa et al. (2008) reported a yield of 44.2 Mg ha^{-1} in an organic production system, a value close to those found in the present study. Evaluating the yields of different onion cultivars, Ricci, Almeida, Guerra, Cocheto Junior, and Ribeiro (2014) obtained a value of 24.09 Mg ha^{-1} for the cultivar Alfa tropical in an organic production system under the same edaphoclimatic conditions used in this study.

The difference in TY obtained in both cultivation years can be explained, at least partially, by two reasons: a) in 2014, the rainfalls were better distributed (Figure 1), which promoted an environment that was more favorable to the occurrence of diseases; and b) there was variation in the installment of the top-dressing fertilization. In 2014, the application of castor cake was divided and resulted in non-mineralized residual material, thus not providing part of the nutrients to the crop. In 2015, the top-dressing fertilization was applied in a single dose (at 30 DAT), which favored higher mineralization.

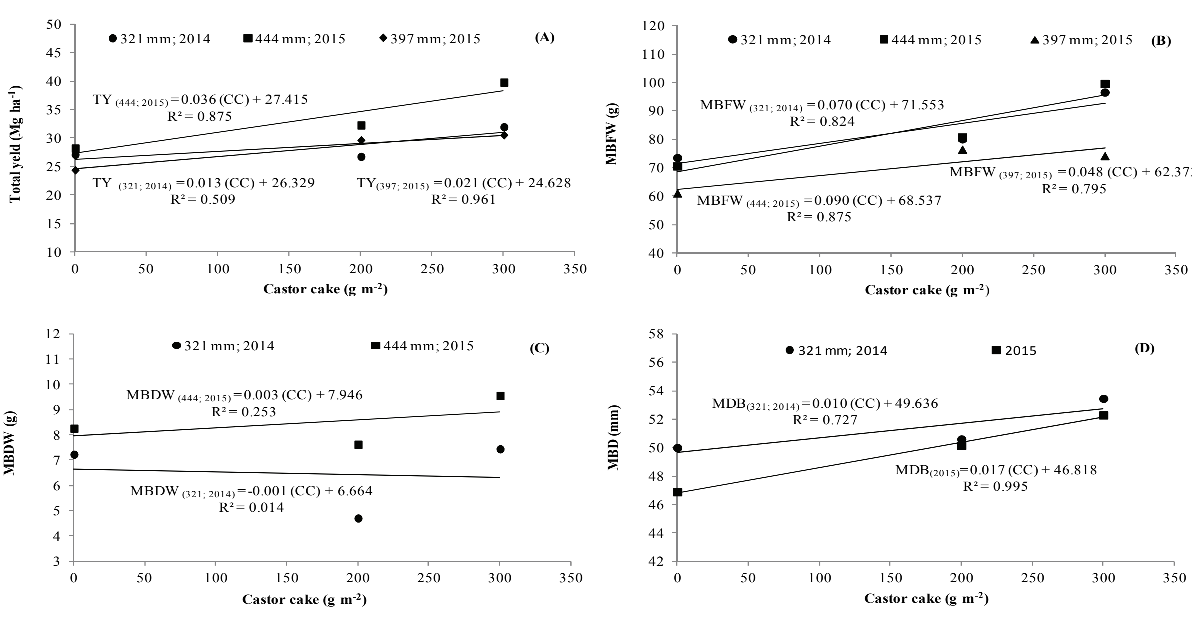

Figure 4. Total yield (TY) (A), mean bulb fresh weight (MBFW) (B), mean bulb dry weight (MBDW) (C) and mean bulb diameter (MBD) (D) for the doses of castor cake at each irrigation depth in both cultivation years (2014-2015). CC: Castor cake.

The percentage of bulbs with diameters greater than 60 mm was positively influenced by the increase in the irrigation levels in both the absence of fertilization and the addition of 300 g m^{-2} dose of castor bean cake in 2014, but it was independent of fertilization in 2015. The increase in irrigation levels favored the percentage of bulbs with a diameter between 41 and 60 mm when 200 g m^{-2} of castor bean was applied in 2014. In 2015, irrigation had an opposite effect, as a larger percentage of bulbs had diameters greater than 60 mm. The highest number of bulbs was included in this classification, as found by Ricci et al. (2014) and Ribeiro et al. (2016). The increase in water deficit favored an increase in the percentage of bulbs with diameters between 30 and 40 mm (smaller class) and with diameter smaller than 30 mm (without commercial value) (Figure 5).

Kumar et al. (2007) attributed this response pattern to the variation in soil moisture because higher water levels promote better water comfort to the plants. Shock, Feibert, and Saunders (1998), Martin de Santa Olalla et al. (2004) and Enciso, Weidenfeld, Jifon, and Nelson (2009) also observed this response pattern in their studies with different irrigation depths in onion cultivation.

Larger percentages of bulbs with diameters greater than 60 mm were found with the application of the 300 g m^{-2} dose of castor bean cake and at irrigation depths of 397 and 444 mm (larger depths) in 2015. A similar effect was observed with the application of this dose at depths of 397 and 278 mm for the percentage of bulbs with diameters between 41 and 60 mm. However, with the application at 444 mm, the percentage of bulbs with diameters between 41 and 60 mm decreased with increasing doses of castor bean cake. This is explained by the high percentage of fruits with diameters greater than 60 mm observed with the increase of castor bean dose, which reduced the percentage of bulbs with both diameters between 30 and 40 mm (smaller class) and diameters smaller than 30 mm (without commercial value) (Figure 6).

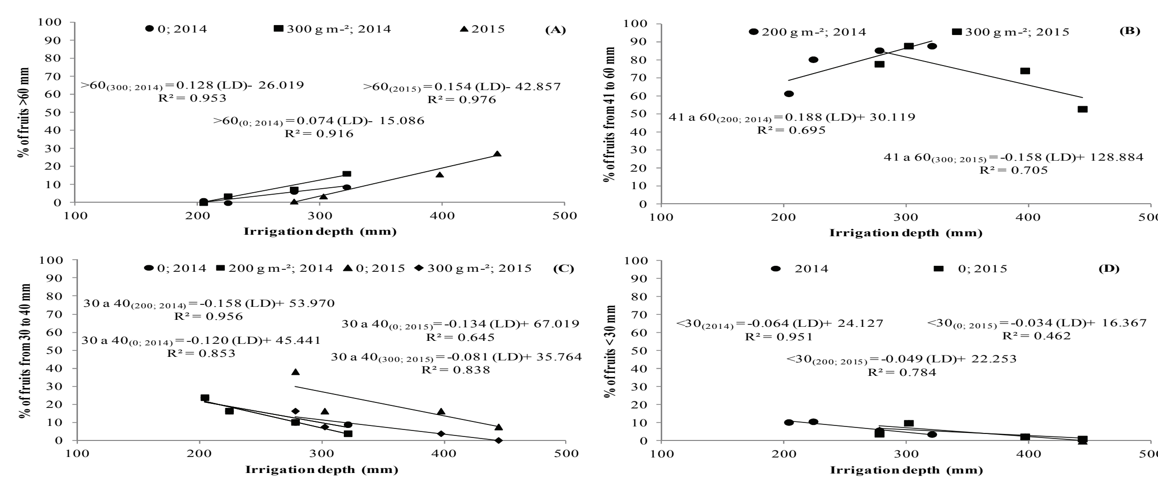

Figure 5. Percentage of transverse bulb diameter in the different bulb classes for irrigation depths in both cultivation years (2014-2015).

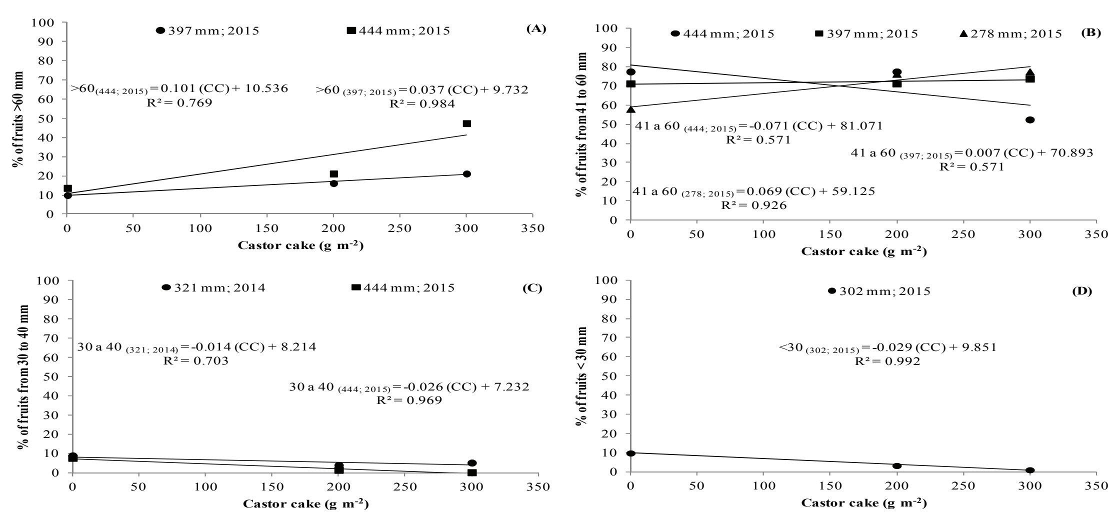

Figure 6. Percentage of transverse bulb diameter in the different bulb classes for the castor cake in both cultivation years (2014-2015).

Water use efficiency (WUE) varied from 99.30 (L4) to 88.86 (L1) kg ha^{-1} mm^{-1} in 2014 and from 100.60 (L4) to 103.85 (L1) kg ha^{-1} mm^{-1} in 2015. WUE was not influenced significantly by the irrigation depths, unlike the irrigation water use efficiency (IWUE), which showed a significant response, with the highest (266.2 kg ha^{-1} mm^{-1} in 2014, 269.7 kg ha^{-1} mm^{-1} in 2015) and lowest (147.5 kg ha^{-1} mm^{-1} in 2014, 172.4 kg ha^{-1} mm^{-1} in 2015) values observed, respectively, for L4 and L1 (Figure 7). Under water deficit conditions, the plant utilizes a survival strategy to develop its root system and create water reserves in the bulb (Zheng et al., 2013), which indicates that even with low water availability in the soil, onion plants can develop bulbs, although they may be of lower quality (Figure 5).

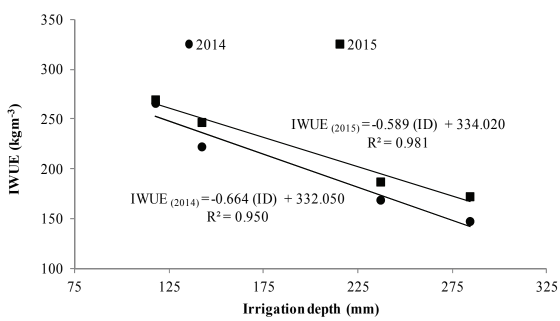

Figure 7. Irrigation water use efficiency (IWUE) for the irrigation depths at each dose of castor cake in both cultivation years (2014-2015).

Conclusion

The irrigation depths used with the automatic device positively and significantly influenced the production of onion bulbs, regardless of the applied dose of castor cake.

The doses of castor cake positively and significantly influenced the production of onion bulbs when higher irrigation depths were used.

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